NASA TM- 77053

NASA TECHNICAL MEMORANDUM

NASA TM-77053

NASA-TM-77053 19830015039

A SIMPLE PROPULSION SYSTEM MODEL FOR THE SIMULATION OF NON-LINEAR DYNAMIC THRUST RESPONSE

Gunther Schänzer and Peter Krauspe

Translation of "Einfaches Triebwerksmodell zur Simulation Nichtlinearer Dynamischer Schubantworten." Zeitschrift fuer Flugwissenschaften und Weltraumforschung, Vol. 2, No. 3, May-June 1978, pp. 195-198.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 MARCH 1983

STANDARD TITLE PAGE

1. Report No. NASA TM-77053	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A SIMPLE PROPULSION SYSTEM MODEL FOR THE SIMULATION OF NONLINEAR DYNAMIC THRUST RESPONSE		5. Report Date MARCH 1983
		6. Performing Organization Code
7. Author(s) Gunther Schänzer and Pater Krauspe		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw- 3542
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes Translation of "Einfaches Triebwerksmodell zur Simulation Nichtlinearer Dynamischer Schubantworten." Zeitschrift fuer Flugwissenschaften und Weltraumforschung, Vol.2, No. 3, May-June 1978, pp. 195-198.

16. Abstract

Presents a mathematical jet engine where the measured transition functions of the engine thrust can be simulated in a quasi-stationary operation as well as in acceleration or deceleration schedules. Because of its simplicity and high fidelity, it is especially suited for representing jet engines in digital simulation programs.

17. Key Words (Selected by Author(s))		18. Distribution Statement Unclassified - Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 11	22. Price

N83-23310#
N-153,168

/19

A SIMPLE PROPULSION SYSTEM MODEL FOR THE SIMULATION OF NONLINEAR DYNAMIC THRUST RESPONSE.

Gunther Schänzer and Peter Krauspe, TU Braunschweig*

Summary: A simple mathematical jet engine description is presented with which the measured transition functions of the engine thrust can be simulated in quasi-stationary operation as well as in acceleration or deceleration schedules. Due to its simplicity along with high fidelity, it is especially suited for the representation of jet engines in digital simulation programs.

1. Introduction

The representation of measured thrust-time sequences of jet engines in digital simulation programs, of whose accuracy particularly high demands are made whenever the jet engine thrust is the primary control quantity of a regulation process, often presents problems. For one, the transition functions (figure 1) can be represented in approximation only by linear control paths of very high order (20 and more) on account of the large ratios of delay time and recovery time. For another, the transition behavior of the thrust changes non-linearly as a function of the engine rpm (figure 2). Finally the time behavior, because of internal energy limitations

---

* Prof. Dr.-Ing. Gunther Schänzer and Dipl.-Ing. Peter Krauspe, Chair for Flight Mechanics of the Technical University, Rebenring 18, 3300 Braunschweig

** Numbers in the margin indicate pagination of foreign text.

of the allowable air mass flux, is dependent on the magnitude of the control quantity jump; here one must differentiate between operation on the so-called steady-state operating line (quasi-stationary operation) and the so-called acceleration/deceleration schedule. The adaptation of a linear control path of high order to the named condition is very costly [1]. The description of the engine dynamics in the phase plane [2] here offers the possibility for a simple and clear representation of the linear and non-linear portion. The model parameters used depend on engine- and flight conditions, such as pressure ratios, air mass throughput, inlet temperature, Mach number, etc. For reasons of simplicity, one must knowingly forego to include the physical relations between the engine parameters into the model, as is generally customary in the simulation of the entire engine [3]. The model parameters of the presented model are gained basically from thrust measurements (ground station test or simulation), which apply for the particular flight condition.

2. Symbols

F	thrust
$\dot{F}$	thrust change with time (= dF/dt)
F_L	idle thrust
F_{max}	maximum thrust
t	time
T_i	time constant
N_2	rpm of the high pressure compressor
$\dot{N}_2$	rpm changes with time (= dN_2/dt)

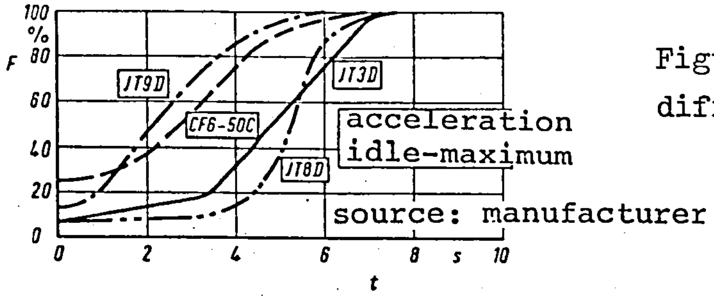

Figure 1: Transition behavior of different jet engines.

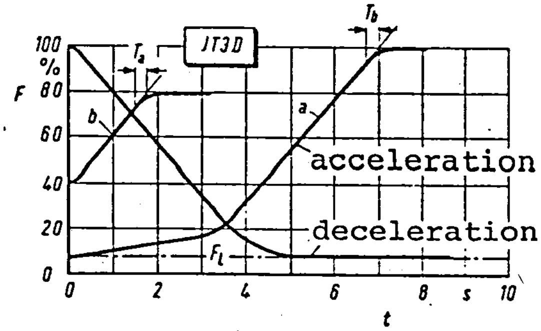

Figure 2: Jump responses of a jet engine (measurements) for a) large and b) small thrust changes.

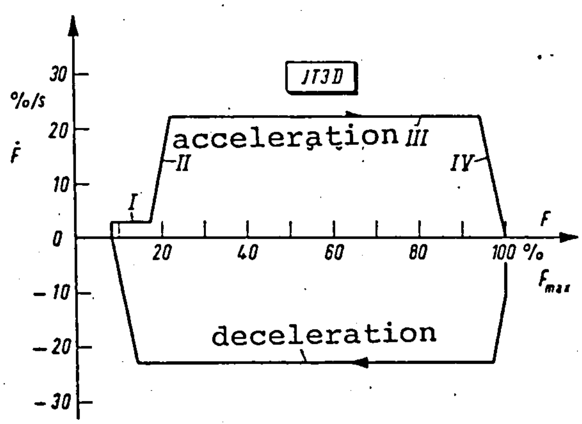

Figure 3: Phase diagram of the thrust sequence of a jet engine.

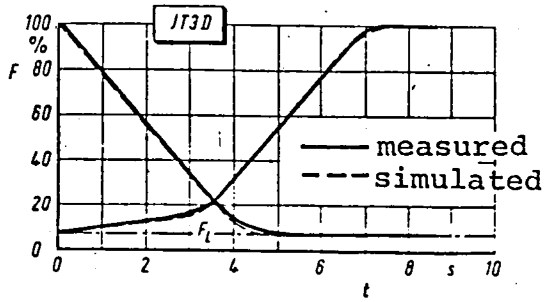

Figure 4: Comparison of measured and simulated thrust curves .

3. Bases and physical relations

The dynamic non-linear engine behavior, such as is presented, e.g., in figure 2, can be approximated (figure 3) with good accuracy by straight lines at least for the multi-shaft engines investigated JT3D, JT9D, CF6-50C in the phase plane F, $\dot{F}$. The desired function F(t) can, since an $\dot{F}$ value is assigned to every value of F, be gained from a simple integration of $\dot{F}$:

$$F(t) = F_0 + \int_0^t \dot{F}(F)\,dt. \tag{1}$$

In figure 4 a plot of the thrust-time curves calculated in this way is plotted along with the measurements on which they are based. As the result of the additional statement of the rpm N_2 of the high pressure compressor, the typical dynamic properties of a jet engine power plant become more pronounced (figure 5). If one subdivides the phase curves in figure 3 and the assigned jump response to a change in gas throttling in figure 5 into subregions, one can find a clear physical interpretation for every individual region:

(I) Starting region

Increase of the engine speed N_2 from idle with nearly constant, relatively small changes in the speed $\dot{N}_{2,1}$. One must remember that for turbine jet-stream engines there is a strong non-linear relation between the thrust and the speed. Thus, one must assign, e.g., to the idle thrust F_L an idle speed of nearly 60% of $N_{2,max}$; thus, the entire thrust spectrum from F_L to F_{max} lies within the remaining 40% of the allowable speed range. In region I one obtains, despite the non-linear behavior of the speed, a nearly constant value of $\dot{F}$.

(II) Transition region to maximum acceleration $N_{2,\ max}$

In the phase plane the slope $\dot{F}/F$ of the phase curve is constant.

(III) Region of constant thrust change $\dot{F}_{max}$ with almost linear dependency on thrust and speed

The acceleration of a multi-shaft jet engine is limited in this range by the pump limitation of the high pressure compressor. In multi-shaft engines the safe distance from the pump limit is guaranteed by engine controllers. Thus, the dynamic behavior and particularly the maximum acceleration capability is determined in region III by the combined action of engine and controller.

(IV) Transition region to the stationary final value

The time behavior corresponds to the behavior of a linear system of first order with the characteristic time constant T_ν (figure 6):

$$\dot{F}(t) = \frac{1}{T_\nu}\left[F_{Nom.}(t) - F(t)\right] = \frac{1}{T_\nu}\Delta F(t). \tag{2}$$

The slope of the phase curve in the phase plane thus is given by

$$\left(\frac{\dot{F}}{\Delta F}\right)_{IV} = \frac{1}{T_\nu} = \text{const.} \tag{3}$$

Let the characteristic time constant of region IV be T_2. If one compares the transition regions II and IV one can find a formal agreement: both sections were given in the phase plane by a straight line slope $\dot{F}/F$. Let the characteristic time constant T_1 be defined in region II analogous to equation (3):

$$\left(\frac{\dot{F}}{\Delta F}\right)_{II} = \frac{1}{T_1} = \text{const.} \tag{4}$$

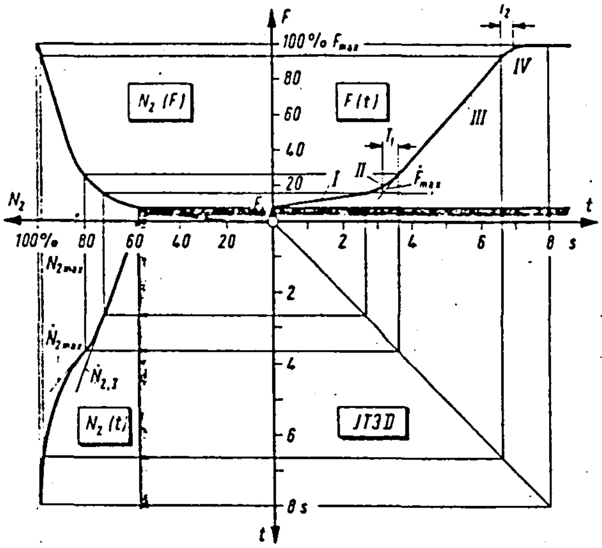

Figure 5: Relations of thrust and speed of a multi-shaft jet engine.

A comparison with figure 5 shows that for the jet engine investigated here one can use the approximation

$$T_1 \approx T_2 = T_\nu \tag{5}$$

These time constants characterize time behavior of the jet engine for small characteristic value jumps ("small time behavior") and lie in the range from 0.25 to 1 second. However, one must note that the model parameters $\dot{F}_{max}$, T_ν, T_1 and T_2 apply each time only for a given ambient- and flight condition. The model parameters presented here refer to ground stand tests under normal atmospheric conditions. As is known from flight measurements, larger values for T_1 and T_2 are obtained at higher altitudes as the result of decreasing air density and the reductions in air mass flow resulting therefrom.

With the aid of the small-time behavior one can also describe those steady state changes which are characterized by relatively small control quantity jumps, which the system can follow without large delays. The characteristic time constant T_ν of the linear system can be obtained by tangent formation directly from the

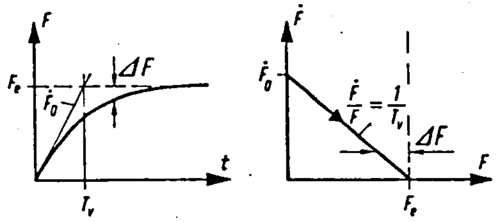

Figure 6: Jump response and phase diagram of a linear system of first order.

measured curve of the transition function of the path, and namely, as shown in figure 2, from the jump response to a) large as well as b) small jumps:

$$T_a = T_b = T_\nu \qquad (6)$$

It is essential that the path can take on practically all possible intermediate values of $\dot{F}$ which lie below the maximum value $\dot{F}_{max}$ of the acceleration line. Thus, the steady-state behavior of the engine is obtained in the phase plane by the number of all points ($\dot{F}$, F) within the phase curve.

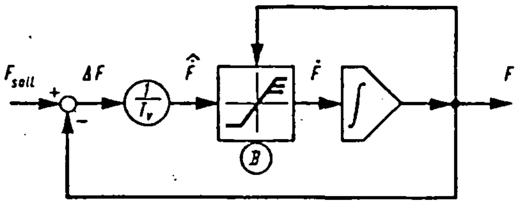

Figure 7: Block switch diagram of the engine model.

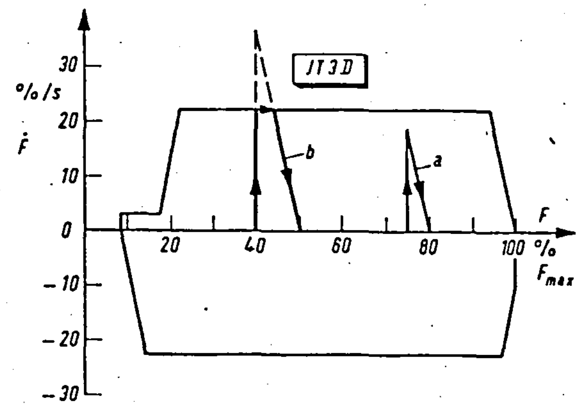

Figure 8: Examples of thrust commands in the phase plane.
a) 75   80% (steady-state)
b) 40   50% (limited acceleration)

3. Model description

The described relations are shown in the block switch diagram in figure 7. According to equation (2) one can determine as a function of the difference between desired- and actual value of the thrust F the initial value $\dot{F}$ of a linear system with the time constant T_{ν}. If the thus determined point (F, $\dot{F}$) lies in the phase plane within the surface bounded by the phase curve (figure 8 a), one is dealing with a change of state, and the desired value $\dot{F}$ is equal to the result from equation (2); if the point lies outside of the phase boundary (figure 8 b), one must put in for $\dot{F}$ the maximum possible thrust change corresponding to the associated value of the ordinate of the phase curve. In figure 7 this action is achieved by the function of the limiting device B whose characteristic line is the phase curve of the jet engine. A subsequent integration of $\dot{F}$ in accordance with equation (1) provides the desired value F(t). The same is true for the operation of the deceleration line or in the region of the steady-state deceleration of the jet engine.

The good agreement of the measured and simulated thrust curves, together with the low programming expenditure, seemed to make the presented jet engine model to be very useful. Applications with detailed numerical calculations are contained in [4].

References

[1] K. Seldner. Simulation of a turbofan engine for evaluation of multivariable optimal control concepts. 1976 Joint Automatic Control Conference, American Institute of Chemical Engineers, New York; ZLDI-Conf.-76-136-003.

[2] W. W. Solodownikow. Basis of automatic control. Vol. II, Some problems from the theory of non-linear control systems. R. Oldenburg publishers, Munich, VEB publishers, Technik, Berlin, 1959.

[3] Digital engine control. Establishment of a simulation model for a multi-shaft double-flow engine. MTU Munich, ZTL 1974, task MUT 3.04/1, EW notification 74/080 (1974).

[4] J. Bergunde. Investigation of deceleration and dead-time effects during cross-wind landings. Chair for Flight Mechanics of the TU Braunschweig, thesis 77-2 (1977)

(submitted on 12/12/1977)

End of Document